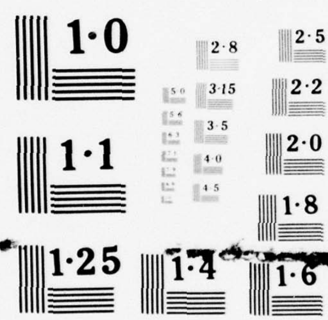
AD-A044 081 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 15/7
AN EVALUATION OF THE EFFECTS OF SELECTED SCHEDULING RULES ON AI--ETC(U)
JUN 77 W D DUNCAN, C H GWALTNEY

UNCLASSIFIED AFIT-LSSR-10-77A NL

1 OF 2
ADA
044081



NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

UNITED STATES AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AN EVALUATION OF THE EFFECTS OF SELECTED SCHEDULING RULES ON AIRCRAFT SORTIE EFFECTIVENESS

William D. Duncan, Jr., Captain, USAF
Curtis H. Gwaltney, Captain, USAF

LSSR 10-77A

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deliterious information are contained therein. Furthermore, the views expressed in the document are those of the author and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

USAF SCN 75-20B AFIT Control Number LSSR 10-77A

AFIT RESEARCH ASSESSMENT

The purpose of this questionnaire is to determine the potential for current and future applications of AFIT thesis research. Please return completed questionnaires to: AFIT/SLGR (Thesis Feedback), Wright-Patterson AFB, Ohio 45433.

1. Did this research contribute to a current Air Force project?

   a. Yes b. No

2. Do you believe this research topic is significant enough that it would have been researched (or contracted) by your organization or another agency if AFIT had not researched it?

   a. Yes b. No

3. The benefits of AFIT research can often be expressed by the equivalent value that your agency received by virtue of AFIT performing the research. Can you estimate what this research would have cost if it had been accomplished under contract or if it had been done in-house in terms of manpower and/or dollars?

   a. Man-years ________ $ ________ (Contract).

   b. Man-years ________ $ ________ (In-house).

4. Often it is not possible to attach equivalent dollar values to research, although the results of the research may, in fact, be important. Whether or not you were able to establish an equivalent value for this research (3 above), what is your estimate of its significance?

   a. Highly Significant b. Significant c. Slightly Significant d. Of No Significance

5. Comments:

________________________ ________________________
Name and Grade Position

________________________ ________________________
Organization Location

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

AFIT/LSGR (Lt Col Barndt)
Wright-Patterson AFB, OH 45433

AU FORM JUL 74 6

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(14) AFIT-LSSR-10-77A REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR-1Ø-77A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) AN EVALUATION OF THE EFFECTS OF SELECTED SCHEDULING RULES ON AIRCRAFT SORTIE EFFECTIVENESS.		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis,
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) William D. Duncan, Jr. Captain, USAF Curtis H. Gwaltney Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Graduate Education Division School of Systems and Logistics Air Force Institute of Technology		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Research and Administrative Management (LSSR) AFIT/LSSR, WPAFB, OH 45433		(11) 12. REPORT DATE June 1977
		13. NUMBER OF PAGES 94
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 106p.		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES APPROVED FOR PUBLIC RELEASE AFR 190-17. JERRAL F. GUESS, CAPT, USAF Director of Information		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Scheduling, Heuristics, Maintenance Scheduling, Unscheduled Maintenance, Simulation, L-COM		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Thesis Chairman: Edward Karnasiewicz, Major, USAF		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

012 250

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LB

The scheduling of tasks in simple and complex environments has been intensely researched. The USAF has shown special interest in research aimed at determining the impact of scheduling effectiveness on mission capability. Much of the recent research emphasizes the need to test, using simulation, selected scheduling rules to determine those that would consistently produce the best results. The availability of the Logistics Composite Model (L-COM) made it possible to test selected scheduling rules in the dynamic maintenance environments of TAC A-7D and MAC C-130E squadrons. Five scheduling rules were inserted into the model to perform the simulations. Results of the simulation indicated that the scheduling rule did impact sortie effectiveness and that rank ordering occurred between the different rules. There was a statistically significant difference between the best and <u>all</u> other scheduling rules for the A-7D. There was no rule for the C-130E which produced statistically significant different sortie effectiveness rates. These results were also compared to an earlier F-4E study that utilized the same five rules.

LSSR 10-77A

AN EVALUATION OF THE EFFECTS OF SELECTED SCHEDULING RULES ON AIRCRAFT SORTIE EFFECTIVENESS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

William D. Duncan, Jr., BS
Captain, USAF

Curtis H. Gwaltney, BA
Captain, USAF

June 1977

This thesis, written by

Captain William D. Duncan, Jr.,

and

Captain Curtis H. Gwaltney

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 15 June 1977

COMMITTEE CHAIRMAN

ACKNOWLEDGEMENTS

We are indebted to many people for their assistance in the preparation of this thesis. First, a deep sense of appreciation is extended to Mr. William F. Drake Drake III, of the Air Force Maintenance and Supply Management Engineering Team for his patience and understanding while explaining the technical intricacies of the Logistics Composite Model. His knowledge and expertise saved us many hours in resolving problems encountered during the operation of the model. We also wish to thank Major Richard F. Glad, Headquarters AFLC, Maintenance Plans Division, for his time and invaluable assistance in explaining the work he had accomplished in the F-4E studies. We additionally must thank our faculty advisor, Major Edward Karnasiewicz, for his advice and patience in permitting us to conduct this thesis in our own manner.

We would also like to thank our wives for their patience and understanding throughout this entire effort.

TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEM

The United States Air Force is deeply concerned about how schedules are prepared and their effects on mission capability (4:1). Although considerable research has been done in the area of scheduling, a satisfactory dispatching rule that consistently maximizes aircraft sortie effectiveness has not yet been determined. The lack of conclusive results from scheduling research can be seen in the fact that USAF directives do not prescribe specific scheduling rules for unscheduled maintenance (32). Although not directed, many scheduling rules are actually used in the maintenance control portion of the maintenance complex. Individual controllers develop their own scheduling rules based on past experience. These rules achieve varying degrees of effectiveness depending on the skill of the controllers.

Several studies have shown that aircraft maintenance operations are conducive to the application of sound scheduling rules:

> . . . [maintenance] is a dynamic environment consisting of multiple independent jobs requiring accomplishment while subject to multiple constraints--the most unpredictable being unscheduled

> maintenance requirements. Jobs occur in a random fashion necessitating the dispatch of finite resources by some priority procedures [15:1].

The overall objective of maintenance scheduling is not merely meeting the scheduled takeoff times, but it is also to reduce the total time that aircraft are out-of-commission for maintenance. A secondary objective is to free resources as soon as possible so that they will be available to work on any new job that might be generated (22:45). By reducing out-of-commission time through effective scheduling, the sortie effectiveness of an organization will increase.

The problem is that a specific scheduling rule which consistently maximizes sortie effectiveness for each aircraft weapons system has not been identified.

Definition of Terms

Scheduling Heuristics. Scheduling heuristics are intuitive *rules of thumb* which "are analogous to priority rules and dispatching rules but in general lack the analytical support to make them acceptable in the scientific world [3:7]." Generally, rules of thumb yield good results but do not guarantee optimal solutions.

Scheduling. Scheduling is the determination of when or in what order individual tasks of a previously selected set of jobs are to be performed. It involves

allocating available resources to specific jobs at definite points in time or in a definite sequence (23:3).

Sequencing. Sequencing is the assignment of a set of directions to a given job for the purpose of processing that job from start to finish. It is concerned primarily with the ordering of an operation on a single machine (29:320).

Dispatching. Dispatching is the assignment of an order in which a number of jobs, all to be processed on one machine, will be processed on that machine (29:320).

Unscheduled Maintenance. Unscheduled maintenance is maintenance required to be performed on an aircraft due to the unexpected failure of one or more aircraft components (2:3).

Sortie. A sortie is a single aircraft flight that starts with a takeoff and ends with a landing (2:2).

Mission. A mission is the act of flying one or more aircraft to achieve the desired goals of aircrew training, proficiency, and evaluation, or the accomplishment of military operations. A mission can consist of one or more sorties (2:2).

Sortie Effectiveness. Sortie effectiveness is a measure of how well a particular organization achieves its established goals. It is the ratio of the number of sorties flown to the number of sorties required, as reflected in the weekly flying schedule (2:2).

The Logistics Composite Model (L-COM). The Logistics Composite Model (L-COM) is a fully developed, validated computer simulation model designed for analyzing aircraft flying programs and support resources. It has been shown that L-COM approximates reality in an operational F-4E environment (15:18).

Justification

AFR 1-1, *Aerospace Doctrine*, states that the United States Air Force exists as an instrument of national power and will be used to support the achievement of national objectives. The capability of Air Force combat units to accomplish their assigned role is dependent upon the quality of assigned aircrews. A significant portion of the training an aircrew receives is accomplished in airborne missions with aircraft. Therefore, the sortie effectiveness of an Air Force flying unit and hence, the contribution this unit makes in accomplishing its assigned role in support of national objectives, correlates directly with the quality and quantity of aircraft provided by a maintenance organization (2:6).

The resources provided to meet the Air Force's mission are continuously decreasing. Although defense budgets are larger in terms of current dollars, purchasing power in real terms has drastically diminished. Therefore, Air Force managers are continually striving to reduce costs. One approach to the reduction of costs is to allocate Air Force maintenance resources more effectively. Dr. Morton B. Berman stated that "improving the scheduling process relates directly to improving the allocation of scarce resources [1:1]." In other words, if a scheduling rule or rules could be shown to sustain improved sortie effectiveness, the benefit to the Air Force would be significant. Three possible benefits are: a unit could accomplish increased numbers of sorties with the same number of aircraft, the same number of sorties could be flown with fewer aircraft, or manpower and other resources could be reduced while maintaining the existing flying requirements.

The importance of sound scheduling is established in AFM 66-1, *Maintenance Management*.

> Maintenance . . . is responsible for insuring that Air Force material is serviceable, safely operable, and properly configured to meet mission requirements. This is accomplished by performing maintenance which includes, but is not limited to, inspection, repair, overhaul, modification, preservation, testing, and condition or performance analysis with maximum efforts expended toward accomplishing these tasks on a preplanned scheduled basis [32:1-1].

An important part of the planning responsibility is scheduling people and equipment to perform tasks at specific times (32:A3-2). A disparity arises in that those responsible for scheduling are not provided with the appropriate scheduling rules which would make their task more effective (32).

The Air Force has continued to demonstrate high interest in developing priority dispatching rules to be used in the aircraft maintenance environment. In 1968, the STALOG (Study of the Automation of the Logistics System at Base Level) program established requirements for developing scheduling rules to be included in the maintenance portion of the system.

> Scheduling rules must be developed for utilization by the STALOG computer in order to achieve a dynamic scheduling capability within STALOG and thereby claim the full range of benefits predicted under the STALOG concept of operation [34.xxi-8].

Much of the research into the effect of military scheduling has been performed by the Air Force through the RAND Corporation. RAND's research has dealt with using computer simulation to represent the scheduling process and predict the outcome of particular aircraft and maintenance schedules (7; 14; 18; 19; 20). Their works added to the body of knowledge by investigating the effects of specific scheduling rules on the environment. As Glad and Pierce point out, the RAND research "suggests a need to develop a rule or combination of rules that will operate

in a dynamic, complex assembly environment [15:3]." A *typical* aircraft maintenance organization may be viewed as a dynamic, complex assembly shop whose output is dependent upon the effectiveness of scheduling.

A simple way of demonstrating the value of using scheduling rules to increase sortie effectiveness is to cite an example from Boyett (3:2-4). In this scenario there are two aircraft, tail numbers one and two, each out of commission for different malfunctions. Each discrepancy requires approximately one manhour for repair. The discrepancies may be cleared by one man in one hour or two men in one-half hour. Two men are available from 0100 to 0200. Maintenance control must decide how to allocate these specialists to the two aircraft. One way is to assign one specialist to each aircraft with the result that both aircraft are repaired by 0200. In this example, both aircraft are in-commission zero percent of the time from 0100 to 0200, but the specialists are utilized 100 percent of this time.

Another allocation method would be to assign both mechanics to tail number one and then to tail number two. Under this method the specialists are utilized 100 percent of the time; however, there is a significant change in aircraft in-commmission rates. One aircraft is back in commission after the first half hour resulting in an in-commission rate of 25 percent (4:2-4).

This simplistic example demonstrates how scheduling rules can be used to affect the mission effectiveness of an organization. Although this is contrary to the "almost universal belief that one cannot increase response capability without either increasing resource quantities or increasing utilization of existing resources . . . [4:2]," this example did so without changing anything but the scheduling rule.

The research of Boyett and RAND emphasize the need to test, using simulation, selected scheduling heuristics to determine those that would consistently produce the best results. If it can be shown that one rule consistently maximizes aircraft sortie effectiveness for each aircraft type, the Air Force could benefit through increased savings. Indeed, the Air Force Logistics Management Center has determined that a significant need exists in this area and has sponsored several research studies in an attempt to determine if such a set of rules exists (30).

Delimitations

The delimitations of this research are as follows:

1. The L-COM was the sole simulation model employed.

2. C-130E and A-7D data had not been validated by MAC or TAC as had the F-4E data. No attempt was

made to physically validate the aircraft input data obtained. However, responsible people in Headquarters Military Airlift Command (for C-130E data) and Headquarters Tactical Air Command (for A-7D data) indicated that the constrained data obtained represented a realistic operational environment (27; 38).

3. The number and length of simulation runs were computer dependent.

4. Actual field validation of the selected heuristic(s) was not accomplished.

5. The structure of the simulation model limited the types of heuristics which could be used in this study.

Objectives

There are two objectives of this research. They are:

1. To compare selected scheduling rules using F-4E, A-7D, and C-130E aircraft data to identify a rule that consistently maximizes sortie effectiveness for each aircraft type.

2. To determine if one rule consistently maximizes sortie effectiveness for all three aircraft.

Research Hypothesis

There is a separate scheduling rule which consistently maximizes sortie effectiveness for F-4E, A-7D, and C-130E flying squadrons and this rule is the same for all three weapon systems.

CHAPTER II

BACKGROUND

The field of scheduling provides varied and interesting problems. When more than one man or one machine have come together, decisions have had to be made concerning the utilization of resources. Requirement dates, process duration, and the availability of resources are but a few of the factors that must be considered before arriving at a decision. Because of its broad applicability, work in the field of scheduling can be found in a variety of different disciplines.

Early Research

Research has been conducted on scheduling theory for many years. This research has centered about investigating specific rules under specific conditions with an ultimate aim of identifying the one *best* rule that will work in all situations. However, this approach resulted in a somewhat fragmented and divergent body of knowledge on scheduling theory.

As early as 1957, J. R. Jackson tried to develop a scheduling rule which would maximize the number of jobs completed on time in an actual shop environment. However, the results of this study have limited application because only one decision rule was tested. This rule was a combination of the shortest processing time (SPT) and due date (DDATE) rules (17:287-295). In 1958, A. J. Rowe studied the use of various decision rules at General Electric Company with a simulation model. This was one of the first studies to apply various scheduling rules in an actual large-scale shop environment (26:154). He found that the choice of a scheduling rule depended on the specific objective of the scheduling problem (minimize job lateness, minimize costs, or maximize labor utilization). It wasn't until 1964, however, that the United States Air Force began to explore the impact of applying scheduling rules in a maintenance environment (7).

From 1957 to 1966 many individual studies were accomplished but no effort was made to correlate and compare their results. However, in 1967 Conway, Maxwell, and Miller tried to organize the current body of knowledge on scheduling theory. Their text, *Theory of Scheduling* (9), incorporated the results of research from such sources as The RAND Corporation, Western Electric Company, The Office of Naval Research, The National Science

Foundation, General Electric Company, Cornell University, Management Science Group, as well as a host of individual contributors. This work serves as a fundamental reference in the field of scheduling theory. It studied the various shop environments investigated and summarized the methods used to solve job shop problems (15:9).

Research in the area of scheduling continued at a rapidly increasing rate using more and more complex methods to study scheduling heuristics and techniques. A thorough and detailed literature review of many of these studies can be found in a research effort by John P. Randle (25). He found that even though research techniques were becoming more sophisticated and the proposed scheduling heuristics more complex, ". . . simple rules could perform as well as, if not better than, the more complex rules [25:59-60]."

Job Shop Environment

Most of the research to date has been directed toward applying scheduling rules to a commercial job shop environment. A problem arises in comparing these research results because the job shop environment can vary with an almost infinite set of characteristics. For instance, repair shops encompass a wide variety of items and repair characteristics ranging from very simple one-source, one-task repair, to very complex

items that require a large number of repair actions in various shops (23:2). A wide mix of manpower and other resources is also possible. In order to accurately compare research results and to perform research on scheduling rules, as much information as possible is needed on the job environment and on the assumptions made about resources.

C. C. New described four fundamental conditions necessary to evaluate and test scheduling heuristics in a commercial job shop environment.

1. *Accuracy of Operational Route Lists.* The exact steps required to repair each item must be listed in detail.

2. *Accuracy of Operation Time.* The time required for each step in the repair cycle must be known within ±20 percent.

3. *Set-Up Times.* Most rules do not take advantage of grouping items, so set-up times are included with each item to be repaired. These job preparation times must be accurately estimated.

4. *Due Dates.* Due dates must be realistically related to the repair times required; otherwise, it would be pointless to attempt to apply scheduling heuristics (24:40)

By addressing these conditions, the actual environment can be more clearly defined. The applicability or

validity of any scheduling research results depends on how closely the model used represents the actual system being studied.

Randle points out that the aircraft maintenance scheduling problem differs from most commercial scheduling problems in environmental structure, and therefore, in the application of scheduling rules (25:53-7). For this reason, a short discussion of the aircraft maintenance scheduling environment is in order.

The objectives of aircraft maintenance scheduling are similar to commercial scheduling problems, i.e., maximize the number of jobs accomplished and minimize the number of late jobs. Specifically, the aircraft maintenance objectives are:

1. To minimize the number of aircraft awaiting servicing

2. To minimize the time an aircraft waits for and is being serviced

3. To maximize the number of on-time takeoffs

4. To maximize the number of jobs completed on time by the maintenance facility.

Even though the objectives of aircraft maintenance are similar to those of a commercial job shop, the structure of the two environments differs somewhat. In the commercial environment, the work product is usually routed to a shop or series of shops and repaired

there. In contrast, the aircraft maintenance environment is more complex. The work product may consist of servicing an aircraft, repairing an item on the aircraft, or repairing an item in a shop. The workers may, therefore, be required to work on the flightline, in the shop, or a combination of both of these. This complex environment greatly increases the difficulty of applying scheduling heuristics to the aircraft maintenance environment (25:53-55).

Scheduling Rules

Scheduling rules may be classified based on their response to changes in the environment. A rule is classified as dynamic if it permits changes in job priorities. A static rule is a rule which assigns a priority to a job and this priority never changes. The main reason for evaluating how rules respond to the environment is that dynamic rules, which incorporate the current state of the system, are more efficient than static rules, which are based on historical events (4:10).

Literally hundreds of different scheduling rules can be derived from the body of knowledge that has developed on scheduling theory. Different rules were developed to try to achieve maximum results in a given environment. Some of these rules are extremely complex while others are relatively simple. The more

complex rules continually reevaluate the status of the job in process. For instance, the "maximum number of remaining operations on product rule (MAXNRD-SPT)" is a complex rule which assigns a priority by evaluating:

> . . . the smallest difference between the maximum number of remaining operations over the jobs in its product and the number of remaining operations on the specific job in queue; priority is reevaluated each time a job is to be selected from queue. Shortest processing time is used as a tie-breaker [20:9].

A simpler rule would be "shortest processing time" (SPT) in which the job with the shortest processing time is repaired first (25:12).

The large number of rules available makes it difficult to accurately select a rule that might maximize production for a given constrained environment. The difficult task of selecting an appropriate rule is made easier if only the "simple" rules are considered. As previously stated, ". . . simple rules would perform as well as, if not better than, the more complex rules [25:59-60]." Indeed, there seems to be a consensus of opinion, with only slight variation, among Minh (22:7), Randle (25:12), Davis (22:8), Elvers (12:63-4), and Boyett (4:18-19) that the following rules are popular and consistently provide good schedules for a general job environment:

First Come, First Served. Jobs are processed in the order of their arrival at the shop.

Longest Job First. Jobs are processed starting with the job requiring the longest processing time first.

Shortest Job First. Jobs are processed starting with the job requiring the least processing time first.

Soonest Due Date Project First. Choose the job with the earliest due date for processing first.

Minimum Job Slack First. Process the job with the least current slack time first. (Slack time is the amount of time remaining before the job must be started if it is to be completed on time).

Minimum Project Slack First. Process the project (a set of jobs) with the least current slack time first.

Simulation

There are two primary means for testing selected scheduling heuristics. The earliest method was to construct an algorithm and solve the model manually through recognized mathematical methods. This method was highly satisfactory in a small job shop environment. However, to evaluate the many interacting variables that can be present in a complex environment such as aircraft main-

tenance, a vehicle was needed that could efficiently deal with the data. Computer simulation provides the means to manipulate large data networks efficiently.

The use of simulation models to represent the job shop environment has been the subject of much debate. Simulations can be very expensive and difficult to construct. Another reason for the lack of simulation studies on scheduling and sequencing problems has been the requirement for a computer with substantial core size and available time (25:24). Conway offers an additional reason:

> I believe that, in general, simulation models take longer to construct, require much more computer time to execute, and yield much less information than their authors expected [8:1].

Perhaps, because of these reasons, comparatively few simulation studies of scheduling and sequencing problems have been published in comparison to studies using analytical techniques.

Early simulation studies developed from actual shop situations were accomplished by Bulkin, Colley, and Steinhoff for the Hughes Aircraft Company and by A. J. Rowe for the General Electric Company. A general simulation study was later developed by Ginsberg and King (5:'26; 14). Only the Hughes and General Electric studies were concerned with analyzing the effects of specific decision rules on various objective functions. As the

advantages of using computers to manipulate large complex data packages became more apparent, the use of simulation models increased.

The RAND Corporation became a leader in using simulation models to represent the maintenance and operational environment. Their research report on the Base-Operations-Maintenance-Simulator (BOMS) indicated there were two criteria for selecting computer simulation in lieu of mathematical methods.

> 1. A large number of relevant factors which interact with each other in a complex manner.
> 2. A number of elements in the system whose behavior is stochastic, (i.e., random, varying with time in some unfixed manner) [14:11].

The operation of an Air Force base meets these criteria. It involves many complex and interrelated variables, many of which are often unpredictable. These jobs occur in a highly random fashion. A major advantage of computerized simulation is that it permits the user to visualize how this dynamic, complex operational environment reacts under actual or hypothetical situations without disturbing the operation of the base itself (13:1). A shortcoming of BOMS and other early simulation models, however, was that they were basically laboratory models and never validated to see if they duplicated the actual environment (2:14).

Glad and Pierce point out that "the ability of simulation models to accurately duplicate the real life

environment has long been suspect and reflects on the acceptance and validity of research results [15:18]." Hence:

> If the simulation model is in complete agreement with the actual shop parameters, then the simulated and actual shop activity would be identical; however, due to the many assumptions built into the simulation model this seldom occurs. Hence one is faced with the question of validity, or the degree to which the assumptions made in the simulation represent the situation in the real shop [10:28].

Hershauer and Ebert suggest the use of a *validated* simulation model is the beginning step in developing "a method for finding a sequencing rule that performs well in any specific job shop situation [16:833]." It is imperative that the simulation model utilized for evaluating the selected heuristics be able to represent the environment being tested. One such model, the Logistics Composite Model, is fully developed and validated and is in existence at Headquarters Air Force Logistics Command (AFLC).

The Logistics Composite Model

The Logistics Composite Model (L-COM) was developed as a joint effort between the RAND Corporation and AFLC to be used by Tactical Air Command (TAC) to forecast required maintenance manning levels to support given flying programs. "L-COM was selected because of its flexibility in that it can portray various maintenance environments through pre-determined flying schedules and

resources [35:1]." Most significantly, however, is that L-COM has been validated in an operational TAC F-4E environment and it duplicates, to a large extent, the operation of an actual F-4E flying unit.

The L-COM model is composed of three individual programs which interact directly without assistance from the user. The model consists of a preprocessor, a main simulation program, and a post-processor. The model functions by scheduling exogenous events (the flying scenario) against a support environment described in terms of task networks. A task is defined as a requirement for resources, whether they be parts, equipment, men, facilities, or time. The task structure of the flying unit is determined by the user and input into the model in the form of networks which describe every task required to accomplish a component repair. The preprocessor translates user-provided data (task networks, reliability factors, resource levels, etc.) into formats required by the main program. It also generates sortie requirements specified by the user (the flying scenario).

As gleaned from Glad and Pierce, the simulation program,

> . . . processes the structural image of the wing and proceeds to operate on specific paramenters necessary to duplicate occurrences that are actually present in a real maintenance environment [15:19].

The model considers the flying schedule and a predeter-

mined priority system which is utilized to provide resources necessary to repair the inoperative component. "Failure clocks," driven by a random number generator, simulate the failure of inoperative parts. The dynamic environment of aircraft maintenance is simulated by the internal logic of the main program. Operationally ready aircraft are generated from the repair actions. The simulation program produces a performance report which can be analyzed by the user to determine sortie effectiveness, resources consumed, required manpower, etc.

The post-processor uses the data produced by the simulation program to provide two kinds of output products showing simulation results as a function of simulation time. These are the operational summary statistics and repair data, both in graphical form (31:5-1--3).

L-COM was designed to be inherently flexible, leaving the degree of detail up to the user. As a result, L-COM has been used extensively for researching Air Force problems. For example, Boyd and Toy evaluated the use of L-COM to measure the effectiveness of computerized aircraft flying schedules at USAF wing level (2:1). Yates and Fritz adapted the Logistics Composite Model for use in evaluating the manpower requirements in support of the DC-130H aircraft (37).

An early use of L-COM to evaluate the effects of different scheduling heuristics was done by Curtis E.

Neumann of AFLC. The Workload and Repair Activity Process Simulator (WRAPS) was designed to simulate the flow of events and use of resources to repair component items in a depot-level repair shop. The WRAPS model was used "in simulation studies of priority decision rules applied to the repair shop environment [23:i]." The model used as its basis the Logistics Composite Model. To adapt L-COM to a depot environment, the simulation driving mechanism was completely redefined from a flying schedule to a workload schedule. "Only minor changes to the network processor logic of L-COM were necessary [23:5]."

AFLC was attempting to determine:

> . . . the effect of priority assignment procedures on the performance of a shop that is pre-loaded with a quantity of work to be produced during a fixed production period [23:ii].

Scheduling heuristics were tested against the shop environment to gain information on the important considerations to use in selecting appropriate rules for a shop scheduling system (i.e., given certain desired shop parameters, which rule best attains these goals). The rules tested in the WRAPS model were primarily the so-called "simple" rules such as shortest processing time (SPT), longest processing time (LPT), a combination of SPT/LPT, LPT/SPT, and SPT and LPT with precedence (23:19). Although no single scheduling rule was always best, the results of the WRAPS research provide a foundation for further evaluation of heuristics.

> The results show the shop operating performance can be affected by establishing a consistent policy of assigning priorities. Priority assignments . . . affect the kinds and amounts of work that can be completed as well as the average flow time of items in the shop [23:36,37].

The most recent use of the L-COM to evaluate the effects of heuristics on sortie effectiveness was done by Glad and Pierce (15). Using F-4E data supplied by TAC, they tested five decision rules against a dynamic maintenance environment. The objective of their research was "to identify a scheduling rule or combination of rules that consistently maximize sortie effectiveness for a TAC F-4E squadron [15:42]." The rules evaluated by Glad and Pierce included the modified first come first served (MFCFS), first come first served (FCFS), shortest mean processing time (SMPT), longest mean processing time (LMPT), and estimated time of completion (ETOC) (15:43). The ETOC heuristic ranked highest in maximizing sortie effectiveness. Glad and Pierce also showed that changing scheduling heuristics does influence performance. Spinner emphasizes the importance of this type of research. He suggests:

> It would be advantageous if one ultimate solution could be adaptable to any industrial setting for the sequencing problems, however, to date only optimal or near optimal solutions for particular settings have been developed [29:319].

Assuming the task networks, resources, and flying scenarios are defined, priority scheduling rules could be tested

against various weapon systems. Using the Logistics Composite Model, it may be possible to identify a scheduling rule that maximizes aircraft sortie effectiveness for a given aircraft.

CHAPTER III

EXPERIMENTAL DESIGN

Input Data

The data for this research was obtained from several sources. The TAC F-4E simulation studies were obtained from Major Glad, Headquarters Air Force Logistics Command. The C-130 input data was obtained from Headquarters Military Airlift Command (MAC). Data for the A-7D was obtained from the Air Force Maintenance and Supply Management Engineering Team (AFMSMET) at Wright-Patterson Air Force Base, Ohio and from Headquarters Tactical Air Command (TAC). These different data packages were contained on magnetic tape. The input data was loaded into the model to simulate C-130E and A-7D operational environments.

The data package and flying scenario are the two basic forms of input required by L-COM to simulate the operation of a flying unit. The flying scenario provides specific flying requirements in terms of number of missions, takeoff times, mission size, and length. The flying scenario also includes the maintenance actions that occur prior to each sortie (preflight, weapons load, etc.) as well as the maximum takeoff time prior to sortie cancellation. Just as in real life, where

operational requirements influence maintenance, the flying scenario is the driving force of the L-COM model.

The second element of input data integral to the model is the data package. This data, which forms a task network, describes the relationship between systems and subsystems, the probability of occurrence of malfunctions, the flow of maintenance and supply activities, the type and length of tasks, and the general rules required to simulate the maintenance environment. Because of the integral relationship of task networks to the model, a further description is provided (31) (see Figure 1).

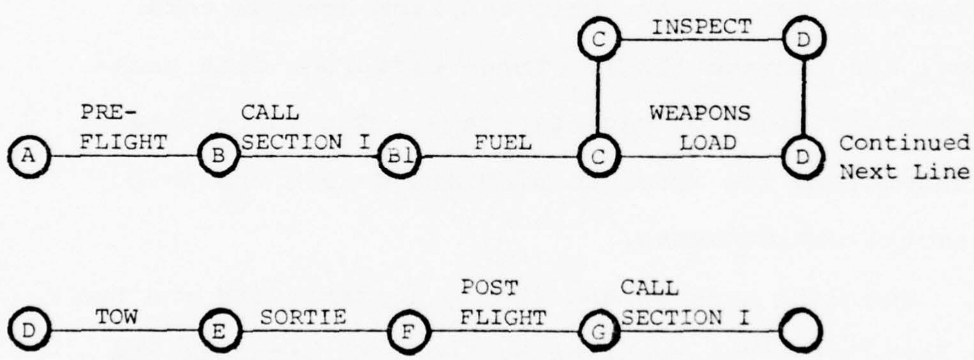


Fig 1. Simplified Task Network

Task networks are basic to the realistic operation of the model. They are composed of tasks defined as requirements for men, parts, or equipment that have a defined relationship with other tasks in terms of series, parallel, or successor tasks (15:22). A "network" starts

with a "node" and then progresses through subsequent nodes becoming more detailed. A "task" name is inserted between nodes, specifying what type of action occurs.

In Figure 1, the sortie is the series successor to the tow task. The inspect task is the series successor to the fuel task and the weapons load is a parallel task to the inspect task. The description of this network or task is flexible in that it can be described by the user to any degree of simplicity or complexity desired. An additional feature permits the network to be designed in sections, thereby reducing the complexity and size of the network input data. Once sections are defined they can be called from several locations within the network. This is portrayed by the task "Call Section I" which might be a maintenance action or actions possible in both pre- and post-sortie periods of time.

Since failure in most equipment tends to be a random process, L-COM simulates the malfunction of items by probabilistic occurrence through the use of "failure clocks." Failure clocks are decremented based on flying time, number of sorties, or other user prescribed intervals. When a clock has been decremented to zero, a failure is simulated and a requirement for resources is generated. The time duration of tasks is controlled by defining the type of failure distribution, average repair

time and variance, and required number of people by Air Force Specialty Code. The network permits a series of tasks to generate requirements for new tasks.

During the simulation, L-COM uses the flying scenario and data package to control the processing of each aircraft through scheduled sorties and through any required maintenance (31:4.1). The model attempts to perform all sorties, but, as in real life, some cannot be accomplished due to the unavailability of aircraft. The lack of sufficient aircraft would be due to malfunctions that cannot be repaired prior to sortie takeoff time. After a sortie is completed, the aircraft undergoes post-sortie inspection and maintenance. When parts or specialists are not available, the required actions become "constrained" and will not be accomplished until the needed resources are available. The time the aircraft is out-of-commission for parts and personnel is reflected in the model's performance statistics as Not Operationally Ready Supply (NORS) and Not Operationally Ready Maintenance (NORM) data. While there are many factors required for L-COM simulation runs, it is L-COM's ability to process these complex factors that makes the model so dynamic and provides the ability to closely duplicate the real world (35:4-7).

In using L-COM to investigate system behavior, the user must address validation. The L-COM model itself was initially validated in the PACER SORT field test (31:1-2). Continued use of the model by various major commands has strengthened the initial validation. The input data obtained for this research is currently being used to forecast manning levels and parts requirements for flying operations. Although this data has not been field tested, as had the F-4E data, the fact that the model continually produces accurate manning figures for operational units increases confidence in the results.

Rule Changes

In order to test the impact of different rules on mission effectiveness, it was necessary to change L-COM's method of setting priorities to sequence tasks awaiting work. This was accomplished by inserting different scheduling rules into the model. The scheduling heuristics chosen were: modified first come first served (MFCFS), shortest mean processing time (SMPT), longest mean processing time (LMPT), first come first served (FCFS), and estimated time of completion (ETOC). These rules were chosen for several reasons. As stated in Chapter II, they were chosen because they are simple, in both concept and application, and yet perform as well as, if not better than, the more complex rules. It was also

shown that there is a general consensus that these rules perform most effectively.

In addition to the reasons already discussed, there are others which more directly justify the selection of these rules for this study. These rules were used by Glad and Pierce (15) to establish the fact that changing a heuristic has a direct impact on sortie effectiveness. They also found that some of these rules consistently produced a higher sortie effectiveness rate. Since the purpose of this study is to see if these rules have the same impact on other aircraft as they did on the F-4E, it will be necessary to use these same five heuristics. Otherwise, a valid comparison would not be possible.

These rules also make the best use of parameters existing within L-COM. They are all based on the same factors which L-COM uses to establish its own internal priorities, i.e., processing time, lapsed waiting time, and priority ranking. For this reason, these rules were easily adapted to the model. The model's internal priority system proved to be a limitation in this study, as well as in the study by Glad and Pierce (15), in that rules which required the establishment of due dates could not be used. Establishing due dates is not possible in L-COM because the model does not account for all tasks required to return the parent job to a service-

able status. This same limitation prevents the testing of a First Arrived First Served rule and also the Fewest Remaining Tasks to Go rule. A brief description of the heuristics used in this study follows:

1. Modified First Come First Served (MFCFS). This scheduling rule is the heuristic utilized by the validated L-COM model. Each possible task is given a task priority ranking in the task network portion of the input data. This ranking is based on the relative importance of the task in relation to repairing an aircraft. A task maintains this assigned priority throughout the simulation. However, when the MFCFS rule is utilized, each task's priority ranking is increased by a time factor as it sits in the awaiting work set. This procedure prevents a task from remaining in the set permanently while higher incoming priority tasks are processed. Since priority ties are possible as a result of this procedure, the shortest processing time is used as a tie breaker to help decide which task should be placed into work. The MFCFS heuristic departs from the traditional concept of a FCFS rule where the awaiting work set is totally ordered by the time a task began awaiting work.

2. Shortest Mean Processing Time (SMPT). The tasks competing for resources are given an initial priority based on mean task processing time. This priority is

used to order the task in the awaiting work set. Ties are broken by using the task priority ranking. This action has the effect of considering all tasks as equally important and working only those with the shortest processing time. The only time the importance of the job is considered is when ties exist, and then the job having the higher priority will be worked first.

3. Longest Mean Processing Time (LMPT). This heuristic is the opposite of SMPT. Tasks are ordered by processing time with ties being broken by the task priority ranking. The tasks with the longest processing time are worked first.

4. First Come, First Served (FCFS). The tasks entering the system are given a priority equal to their arrival time in days elapsed since the start of the simulation run. The awaiting work set is totally ordered by the arrival time of a task in the system. Task priorities are increased in the awaiting work set based on the length of time the task is in the set.

5. Estimated Time of Completion. This heuristic combines the features of FCFS with those of SMPT. Tasks which are entered into the awaiting work set are ordered according to the time they entered the system plus their mean processing time. This combination of attributes results in a computation of the estimated time of completion for the task. The awaiting work set is totally

ordered by this estimated time of completion with the task priority ranking used to break ties. The use of the task priority ranking to break ties assumes, as it did in the other four heuristics, that tasks identified by the user as having a higher relative importance will be worked first (15:29-32). Table 2[1] (see Appendix)[2] lists the equations used to obtain priorities with each heuristic.

As previously stated, the L-COM model uses the MFCFS heuristic. Therefore, to change this rule and run a simulation utilizing a different rule, it was necessary to make several changes to the L-COM computer program. Table 3 shows the program changes that must be made to change the scheduling rule used by the model.

The program for L-COM is maintained in object form in a file called LCOMKSTR. However, in order to make a simulation run, LCOMCSTR is the program used. LCOMCSTR "marries" the input data with the model program (LCOMKSTR) and the rule change, simulates the conditions requested, and produces the required output. The rule changes are made using a short alter program which calls LCOMKSTR, makes the rule change, and writes to LCOMCSTR. This process is depicted in Figure 2.

---

[1]Table 1 appears on p. 48.

[2]Tables 2-22 appear in the Appendix.

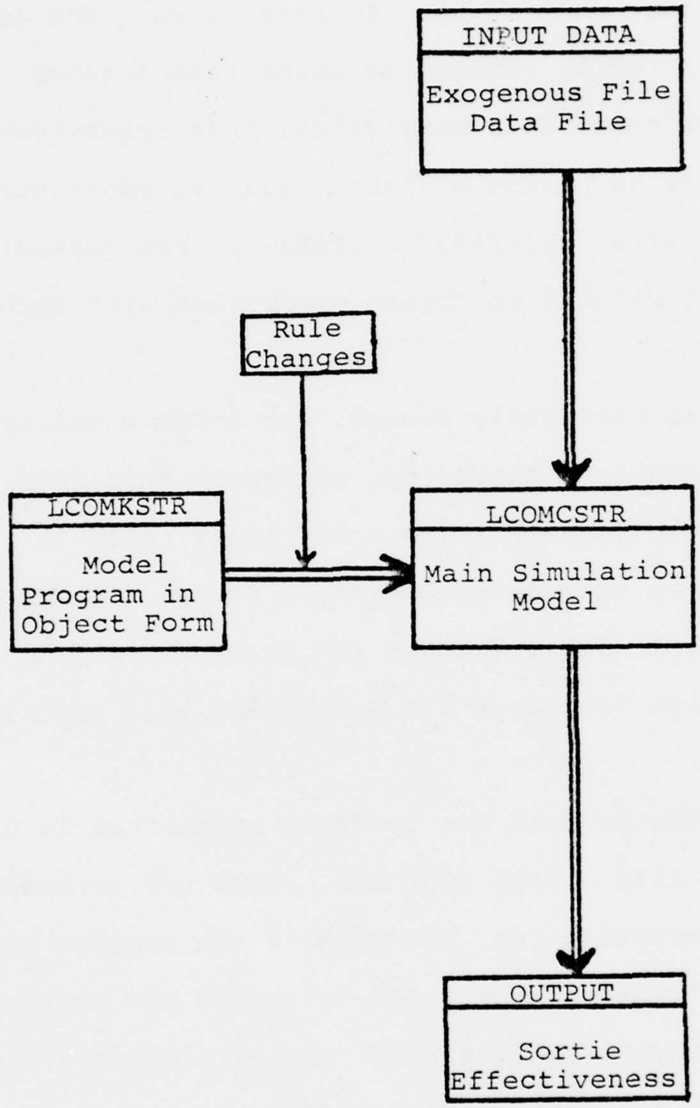


Fig. 2. L-COM Program Flow

Simulation Runs

The C-130E data was received as a complete package from MAC. However, the A-7D data had to be obtained from two sources. The A-7D data base and flying scenario were received from the AFMSMET. The appropriately constrained parts and manpower files had to be obtained from TAC. These C-130E and A-7D files were constrained to accurately represent an actual flying squadron.

A pilot study was initiated using sample F-4E input data to evaluate the operation of the L-COM model. First the data base and flying scenario were loaded to test the ability of the preprocessor (input program) to produce an initialization tape and an exogenous events tape. These two tapes were produced allowing the sample data to be run against the main simulation program. The results of this pilot study replicated the earlier sample runs of Majors Glad and Pierce (15:33). The sample problem was also used to determine the ability of the L-COM model to replicate performance data over identical runs. The pilot runs did indeed produce identical results when operating with identical input data.

In order to process the input data a change needed to be made to the model. As discussed in Chapter II, the preprocessor portion of L-COM translates user provided data into formats required by the main simulation program. A key function of the preprocessor is to

establish the dimensions of the variables used in the simulation. The preprocessor program used for this study, as well as the F-4E study by Major Glad and Major Pierce, was obtained from Mr. William F. Drake III, AFMSMET (11). There are numerous permanent files which the preprocessor program accesses during execution. The dimensions of these files were adequate with the exception of the INPTINIT file. Because of the large size of the C-130E network, the array dimensions of this file had to be expanded to accommodate the input data. The changes listed in Table 4 were made to this file and stored on computer file space under the label INPTINI.

The processed C-130E data was loaded into L-COM and all resources (manpower, parts, etc.) made unconstrained. This was accomplished by multiplying each resource factor by ten. The unconstrained run provided a check for problems in the data base which could create artificial constraints during the final "constrained" runs (31:4-17). During the unconstrained runs, two problems were encountered. The first problem was indicated by Error Message 13, "Trace of Calls in Reverse Order," which appeared in the performance summary. Investigation revealed that some network values used in defining a distribution were not recognized by the AFLC version of L-COM. The values were redefined by adding the changes on lines 110 through 170 of Table 3. The second problem

was encountered after approximately eight-five days of simulation. Because of the size of the C-130E network, the array for the tasks to be expedited was inadequate. The size of this array was increased by adding lines 180 through 230 as shown in Table 3.

The processed A-7D data was also loaded into L-COM and all resources made unconstrained. These trial runs were successful and no problems were encountered. Both the C-130E and A-7D unconstrained studies were conducted using the model's existing random seed of eighty-five (a starting value for the L-COM random number generator).

After successful unconstrained runs, the constrained data for both aircraft was then entered into simulation. Tables 5 and 6 list the manpower and spare parts authorizations used in Glad and Pierce's F-4E simulation studies. Tables 12 and 13 list the manpower and spare parts authorizations used in the A-7D study. Tables 19 and 20 list the manpower and spare parts authorizations used in the C-130E study. In Glad and Pierce's study the equipment authorizations were constrained for two Aerospace Ground Equipment units, designated as AM100 and MC120, at five and three units each, respectively. Equipment authorizations for the A-7D and C-130E were kept unconstrained. Since the objective of this research was to determine the level of sortie effectiveness based on the introduction of a given heuristic,

only the heuristic and the random number generator seed were changed. All other parameters (manpower, parts, length of run) were held constant for each constrained run. The length of simulation runs for each aircraft was calculated to conform with the work of Glad and Pierce and provide model stability (15:24).

The length of the simulation runs for each aircraft varied depending on the time it takes the model to reach a steady state. The problem is that the initial results of a simulation are biased by the set of values used to "start" the system. Successive results are less dependent on the initial starting conditions so that eventually results are independent of the initial conditions. Most authors agree that the influence of the "warm-up" period must be minimized prior to analyzing the results of a simulation. Shannon discussed three ways to accomplish this.

> 1. Use long enough computer runs so that the data from the transient period is insignificant relative to the data from the steady state condition.
> 2. Throw out or exclude some appropriate part of the initial period of the run.
> 3. Choose initial starting conditions which are more typical of the steady state condition and thus reduce the transient period [28:296].

Warm-up period bias for this research was minimized by using the second method. The length of the warm-up period for each aircraft had previously been determined by the personnel from which the input data was

obtained. MAC personnel determined that the warm-up period for the C-130E simulation was sixty days. However, AFMSMET personnel indicated that only thirty days were required for the A-7D simulation to reach steady state. The length of simulation runs for this research was adjusted to include this appropriate warm-up time and permit analysis of sixty days of steady-state time. Therefore, each C-130E simulation was executed for 120 days and the A-7D for 90 days.

Each heuristic was tested against the four random seeds used by Glad and Pierce: seeds 13, 15, 85, and 93. A total of twenty simulation runs was obtained for the A-7D. Because the C-130E input package was so large, a complete series of twenty runs was not obtained for this aircraft. Reasons for this will be discussed later.

Results of each run were obtained through normal use of the simulation model's output functions. The sortie effectiveness measure used to evaluate the effect of each heuristic is provided in the summary statistics of the output. The ANOVA statistical technique was used to determine the degree of influence of each heuristic on the sortie effectiveness rates.

CHAPTER IV

ANALYSIS AND RESULTS OF SIMULATION

Operational results for each simulation run were provided in the performance summary report. This report listed the sorties requested, sorties accomplished, and sortie effectiveness (ratio of sorties accomplished to sorties requested expressed as a percentage) for each run. The sortie effectiveness rate is the performance measure used to evaluate the effect of each rule. This data is listed in Tables 7, 14, and 21 for the F-4E, A-7D, and C-130E aircraft, respectively. As shown in these tables, the simulation runs produced differences in sortie effectiveness rates as a result of changing scheduling rules and random number seeds. For example, in Table 7, the MFCFS rule produced a sortie effectiveness rate of 90.35 with seed 13 and 88.11 with seed 15. To determine if the differences in sortie effectiveness rates were due to chance fluctuations or were in fact significantly different, a statistical test using the ANOVA (Analysis of Variance) technique was used.

The ANOVA procedure is a statistical technique that assesses the effects of one or two independent variables (rules, seeds) upon a dependent variable (sortie

effectiveness). It permits the comparison of three or more means simultaneously without degradation of the overall confidence of the test.

Analysis of F-4E Data

The F-4E data was extracted from the simulation studies conducted by Major Glad and Major Pierce (15). Each run simulated an F-4E operational environment for eighty days. This included a warm-up period of twenty days and sixty days of steady-state operation. Each of the five heuristics were tested against four random seeds; seeds 13, 15, 85, and 93. A total of twenty runs was obtained.

A two-factor ANOVA test was performed to determine if the difference in sortie effectiveness was due to the effect of the rule changes, the seed changes, or both. Table 8 was constructed showing the ANOVA calculations. Two F ratios were computed in the table. The first F-statistic (F_s) was used to test for significant differences between the means of the rules. The second F_s was used to test for significant differences between the means of the seeds. A critical value for F (F_c) was then selected for an alpha level of .05 or a 5 percent level of significance. The F_s and the F_c were then compared using the following decision rule: If $F_s > F_c$, reject the null hypothesis, H_0. The null hypothesis

could not be rejected for the seeds where the F_s was less than the F_c. This indicates that the differences in the means for the seeds are due to chance fluctuation and are not statistically significant. This result can be anticipated, as changing the random seed should not change the scheduling philosophy within the model but should only change the random distribution of failures.

The null hypothesis could be rejected for the rule means since the F_s was greater than the F_c. This indicates that there are significant differences between rule means. The two-factor ANOVA was collapsed to a one-factor ANOVA to decrease the strength of the test on the rules and determine if the differences of the means would still be statistically significant. Table 9 displays the one-factor ANOVA calculations. Again, the F_s was greater than the F_c, indicating there was a statistical difference between at least two rules.

To determine if more than one pair of rules was significantly different and which pairs these were, the H. Scheffé Simple Pairwise Difference of Means technique was used (36:225). Tables 10 and 11 show that there is a statistical difference only between ETOC and MFCFS, and SMPT and MFCFS. However, no one rule was statistically better than *all* of the other rules. The rules can be rank ordered with ETOC producing the highest

sortie effectiveness rate followed by SMPT, FCFS, LMPT, and MFCFS respectively.

Analysis of A-7D Data

For the A-7D, each simulation was run for a period of ninety days. This included thirty days warm-up time and sixty days of steady-state operation. The five heuristics were tested against the same random seeds used in the F-4E study. A total of twenty runs was obtained.

The two-factor ANOVA technique was applied to the sortie effectiveness data as shown in Table 15. The results of this test again indicate that a change in the random number seed does not significantly affect the sortie effectiveness rate but a change in the rule does. The two-factor ANOVA was then collapsed to a one-factor ANOVA (Table 16). This test indicated there was still a statistically significant difference between at least one pair of means. The H. Scheffé technique was applied to the data to determine which rules differed. The results are displayed in Tables 17 and 18. In this case, MFCFS was significantly different from *all* of the other rules. However there was no significant difference among ETOC, SMPT, FCFS, and LMPT. The rules can be rank ordered with MFCFS producing the highest mean sortie effectiveness rate followed by ETOC, LMPT, SMPT, and FCFS respectively.

Analysis of C-130E Data

For the C-130E, each simulation was run for a period of 120 days. This included sixty days warm-up time and sixty days of steady-state operation. The five heuristics were tested against the same random seeds used in the F-4E and A-7D studies. However, a total of only sixteen runs was obtained.

The size of the C-130E package created several problems and limited the final number of runs obtained. One problem was the amount of computer memory required to conduct the simulation. The C-130E package requires over 160,000 words of memory as compared with 125,000 words for the A-7D and 115,000 words for the F-4E. The useable memory of the computer utilized in this study was limited to 188,000 words. Another problem was the amount of computer processor time required to execute the simulation. Each C-130E run required 4-1/2 to 5-1/2 hours to execute. This combination of memory size and excessive processor time restricted C-130E simulation runs to the weekend. Overnight turn-around of runs was not possible as it was in the case of the A-7D and F-4E. The time required to acquire the data package, load the data into the model, rectify problems encountered, and obtain twenty pure runs exceeded the time available for this study.

The two-factor ANOVA requires a full matrix of values. Since only sixteen runs were obtained for the C-130E, there were missing values in the ANOVA table. This meant that the test of significance of the rules in the presence of the seeds could not be conducted. As anticipated, the F-4E and A-7D data confirmed that changing random seeds did not significantly affect the sortie effectiveness rates. It could therefore be inferred that changing seeds would also not significantly affect the C-130E sortie effectiveness rates. Hence, a test of the effect of the rules on the sortie effectiveness rates would be adequate. The one-factor ANOVA technique was the appropriate statistical test to use in this case. The one-factor ANOVA calculations are shown in Table 22. In this case, the null hypothesis could not be rejected. Changing the scheduling rule did not significantly affect the sortie effectiveness rates. Even though there was no statistical difference between means, the rules could be rank ordered from highest to lowest in the following manner: MFCFS, FCFS, ETOC, SMPT, and LMPT.

A Comparison of Scheduling Rules

Table 1 summarizes the relative ranking of the rules by weapon system. This table lists the ranking of each rule from one to five, with one representing the

TABLE 1

A COMPARISON OF RULES AMONG WEAPONS SYSTEMS

Rules	F-4E	A-7D	C-130E
Modified First Come First Served	5	1	1
First Come First Served	3	5	2
Shortest Mean Processing Time	2	4	4
Longest Mean Processing Time	4	3	5
Estimated Time of Completion	1	2	3

highest effectiveness rate. For the A-7D and C-130E studies, the MFCFS rule produced the highest sortie effectiveness rate. This differs from the F-4E study in which the ETOC rule produced the best rate. Although ETOC was not the best performer for the A-7D and C-130E studies, it did rank relatively well at two and three, respectively. The SMPT rule, which also ranked relatively high in the F-4E study, only ranked fourth for both the A-7D and C-130E aircraft.

It should be noted that in the A-7D study, the difference in sortie effectiveness means of the second through fifth ranked rules was only .64 percent. This could be interpreted to mean that one of these rules is just as effective as another. It is important to note, however, that MFCFS is significantly better than

any of these four rules. The difference between MFCFS and ETOC, the second ranked rule, is 4.86 percent. In other words, if 250 sorties were requested, twelve additional sorties would be generated by using the MFCFS rule in lieu of the ETOC rule. The final chapter will address the conclusions drawn from the study and possible research extensions.

CHAPTER V

CONCLUSIONS AND FUTURE RESEARCH

Conclusions

The objective of this research was two-fold. First, selected scheduling rules were compared using F-4E, A-7D and C-130E data to identify a scheduling rule that consistently maximizes sortie effectiveness for each individual aircraft type. The second objective was to determine if one rule maximizes sortie effectiveness regardless of the aircraft type.

One rule was found to maximize sortie effectiveness for the A-7D. The MFCFS rule produced significantly better results than any other rule tested. In contrast, no rule was found to be significantly better than any other rule for the C-130E. This parallels the findings for the F-4E in which no rule was found which would consistently maximize sortie effectiveness.

No rule was found to maximize sortie effectiveness for *all* three aircraft. An *a priori* hypothesis was that since ETOC produced the best results for the F-4E, it would also produce the highest sortie effectiveness for the A-7D and C-130E. This was not the case, however. While ETOC ranked first for the F-4E, it

ranked second for the A-7D and third for the C-130E. It should be noted that even though ETOC ranked second for the A-7D, there was only a .64 percent difference between it and the fifth ranked rule.

Although no one rule ranked best for all three aircraft, the MFCFS rule did rank number one in the A-7D and C-130E studies. This was quite interesting since this rule ranked last in the F-4E study. In an attempt to explain this disparity, the characteristics of the three aircraft packages were examined. Although no conclusive reason was found which would explain the difference, the number of aircraft in each package might be considered. The C-130E and the A-7D aircraft packages were relatively large at thirty-two and forty-eight aircraft each; whereas, the F-4E package was much smaller with only eighteen aircraft authorized. Although this observation was considered noteworthy, no attempt was made to support this hypothesis in this study.

The disparity in the performance of the MFCFS rule for the three aircraft warranted a more in-depth examination of the rule itself. When this rule is utilized, tasks are ordered on a FCFS basis within priority groupings. In case of a tie (a result of the combination of priority and arrival time), the task with the shortest processing time is worked first. The characteristics of this rule parallel the decision process

used by many aircraft maintenance controllers. As the controller is notified of a job, he must first ascertain the priority of the task. Within each priority grouping, the controller considers the order of arrival and the processing time in determining which task should be worked next.

It is also interesting to note that the MFCFS rule is inherent in the Logistics Composite Model. The fact that this rule closely parallels the decision process in an actual maintenance environment increases confidence in the validity of the model.

Future Research

The Logistics Composite Model has unlimited potential for future research in the aircraft maintenance environment. This is especially true with the introduction of L-COM II (written in Simscript 2.5) which is an even more dynamic and comprehensive model. Even with L-COM II, however, the user must remain aware of one constraint. Data packages the size of the C-130E are highly computer dependent. The requirement for large memory size and long periods of processing time severely limits timely turn-around of results. These variables should be seriously considered before initiating future research studies which require large data networks.

Given this caveat, L-COM is still a valuable tool for use in future research.

This research and the research of Majors Glad and Pierce evaluated the performance of only five heuristics. Many additional heuristics could be applied to the F-4E, A-7D, and C-130E to determine if a different rule performs better than the five rules tested in this study.

Alternatively, the performance of different aircraft could be examined using the MFCFS, FCFS, SMPT, LMPT, and ETOC heuristics used in this study. Perhaps by conducting continued research using these same scheduling rules, significant trends will become evident and a set of scheduling rules developed which can be used to increase sortie effectiveness as conditions warrant.

Another possible area of research would be to determine if the number of aircraft utilized in the flying scenario has an impact on the relative ranking of the scheduling rules. This could be accomplished by using one weapon system and making simulations with the five heuristics and a small authorization of aircraft and then performing the same study using a large aircraft authorization.

The resources provided to meet the Air Force's mission are continually decreasing. To effectively control these limited resources, Air Force managers must

constantly strive to improve methods of accomplishing their mission. Effective scheduling provides an important means to that end. For this reason, continued research in the area of scheduling is warranted.

APPENDIX

TABLES

TABLE 2

PRIORITIES FOR EACH HEURISTIC

Heuristic	Equation*
MFCFS	Priority = TPRI
SMPT	$= 10^4 \times$ Mean Processing Time + TPRI
LMPT	$= 10^4 \times \left(\frac{1}{\text{Mean Processing Time}}\right) +$ TPRI
FCFS	$= 10^2 \times$ Time
ETOC	$= 10^4 \times$ (Time of Arrival + Mean Processing Time) + TPRI

*TPRI is the Task Priority Rating.

TABLE 3

HEURISTIC CODING USED IN L-COM

Basic Program Changes

```
$       UPDATE LIST
$       ALTER 20,20
+N JBEND8     4
$       ALTER 26,26
$       ALTER 36,36
+N MSN  8   1  N PRI    73     SI
$       ALTER 94,94
+T UREC 4
$       ALTER 98,98
+               T UVALU 3      SF
$       ALTER 1436
     LET ICHG = QI * 100.
     IF (ICHG) NE (50), GO TO 707
     LET DRAW = AA
     GO TO FIN
$       ALTER 1436,1436
   707 LET QPES = QI * B
$       ALTER 4347,4347
     DIMENSION LID(35), LIQ(35), LDEF (35), LBJ(100)
$       ALTER 4552,4552
IF(M)LE(99), GO TO 100
$       ALTER 4556
        STOP
```

TABLE 3--Continued

Specific Rule Changes

MFCFS	ALTER 998,998 LET PRI (JBEND) = TPRI(KTID)
FCFS	ALTER 998,998 LET PRI (JBEND) = TIME * 100
SMPT	ALTER 998,998 LET PRI (JBEND) = 10000. * DEL + FLOAT (TPRI(KTID))
LMPT	ALTER 998,998 LET PRI (JBEND) = 10000. * (1./DEL) + FLOAT (TPRI(KTID))
ETOC	ALTER 998,998 LET PRI (JBEND) = 10000. * (TIME + DEL) + FLOAT (TPRI(KTID))

Other Changes

FCFS SMPT LMPT ETOC	ALTER 1010,1010 195 IF (MSN) NE(0), LET PRI (JBEND) = PRI (JBEND) - 10 + MSNPR (MSN) ALTER 3181,3181 25C LET Y = IPR ALTER 4557,4557 LET X = -IPT

TABLE 4

INITIALIZATION PROGRAM CHANGES
(INPTINI FILE)

Line No.	Array Variable	Old Dimension	New Dimension
40	NCTRL	5,300	7,700
45	NNODE	3,500	4,100
51	NTASK	3,800	4,500
60	NRES	600	500
69	NFAIL	500	400
74	NEIT	550	100

TABLE 5

F-4E MANPOWER AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATIONS

Air Force Specialty Code	Shift Authorizations (24 One-Hour Shifts)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
301X0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
301X1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1
301X3	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
301X4	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2
322Q1	10	10	10	10	10	10	10	10	10	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
325X0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
325X1	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3
402X0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
421X2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	2	2
422X1	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	2	2
422X2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
423X0	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2
424X0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
431C1	32	32	32	32	32	32	32	32	32	32	28	28	28	28	28	28	28	28	28	28	28	28	32	32
431C5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
431C6	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	0	0
432X0	9	9	9	9	9	9	9	9	9	9	12	12	12	12	12	12	12	12	12	12	12	9	9	9
432X5	0	0	0	0	0	0	0	0	0	C	5	5	5	5	5	5	5	5	5	5	5	0	0	0

TABLE 5--Continued

Air Force Specialty Codes	Shift Authorizations (24 One-Hour Shifts)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
462X0	40	68	68	68	68	68	68	68	68	48	48	48	48	48	48	48	48	40	40	40	40	40	40	40
531X0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
532X0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
534X0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
536X0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
533X0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
922X0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Major Richard F. Glad, USAF, and Major Robert T. Pierce, USAF. "A Comparison of Selected Scheduling Heuristics for a TAC F-4E Maintenance Organization." Unpublished master's thesis. SLSR-23-76B, AFIT/SL, Wright-Patterson AFB OH, 1976.

TABLE 6

F-4E SPARE PARTS AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATIONS

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
111AA	1	1425B	1
111HM	1	14310	1
111KC	1	1431B	2
111KH	1	1431J	7
111KJ	4	1432F	4
111KL	2	1442C	2
111KQ	4	1442D	2
111KS	3	1455C	2
111KT	5	1455E	2
1132C	5	14610	1
1231H	3	2371A	1
1233K	1	23730	2
1236K	2	2381A	2
1325A	1	2381M	2
1325D	11	2392A	5
1333C	25	4111H	2
1333A	1	4112B	2
1334B	4	4112M	3
1334C	2	4113A	2
1342E	3	4114G	2
1343B	2	4114J	3
1344A	1	4114K	2
1344C	4	4153F	2
1344K	6	4153G	1
1344L	7	42330	1
1344M	8	42610	3
1352A	3	42630	6
1411A	3	4511B	8
1411F	2	4511A	2
1422B	2	4511K	8

TABLE 6--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
4513A	1	71H2Q	3
45130	3	71H2U	4
4521A	2	71H3L	3
4623A	2	71H3U	3
5623B	1	71H4A	2
4642D	2	71H4L	3
4644C	4	71H4R	3
471AA	4	71H50	1
4721C	7	71H5A	2
47210	3	71H60	2
511AA	2	71LB0	2
511AB	4	71LC0	1
511AD	2	71LD0	1
511AE	3	71LE0	1
511AF	3	71LJ0	4
511AG	6	71L0A	3
511AJ	2	71MA0	3
512AA	5	71ME0	2
512CL	2	71MH0	2
512CM	2	71NA0	3
513B0	4	723A0	1
513E0	3	723B0	2
513H0	5	731B0	2
513HB	5	731C0	2
5211A	2	731D0	1
522B0	1	731E0	2
522E0	1	730ED	2
52240	6	631F0	3
52270	8	731G0	5
71B20	8	731H0	5
71B2A	4	731J0	5
71B2E	3	731L0	4
71H10	2	731M0	2
71H20	1	731N0	5
71H2A	3	73510	3

Table 6--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
73520	2	74BT0	1
73530	1	74BU0	1
74BA0	2	74BUB	1
74BB0	2	74BUC	1
74BC0	1	74BUF	1
74BCA	1	74BUL	1
74BCC	1	74BUM	1
74BD0	1	74BUN	2
74BDD	1	74BUR	1
74BE0	3	74BUS	1
74BF0	3	74BV0	1
74BG0	1	74BVE	3
74BH0	4	74BVG	3
74BJ0	2	74BVR	4
74BK0	1	74BVS	1
74BL0	2	74370	1
74BM0	2	74810	1
74BN0	1	74820	1
74BPO	1	78440	3
74BPB	3	75B10	1
74BPH	2	75B40	1
74BQ0	1	77J10	2
74BQA	1	77J2A	1
74BR0	2	77J2B	1
74BS0	1	9612B	1

TABLE 7

F-4E TWO-FACTOR ANALYSIS OF VARIANCE DATA

Heuristic	Seed				
	i=13	15	85	93	Heuristic Mean = $\bar{X}_i$
MFCFS	90.35	88.11	87.42	86.73	88.15 = $\bar{X}_1$
FCFS	91.82	89.16	88.89	91.20	90.27 = $\bar{X}_2$
SMPT	90.66	91.28	90.89	90.82	91.16 = $\bar{X}_3$
LMPT	89.51	88.89	90.04	90.66	89.775= $\bar{X}_4$
ETOC	92.51	91.59	92.05	90.12	91.57 = $\bar{X}_5$
Seed Mean = $\bar{X}_j$	90.97	89.81	89.86	90.11	

NOTE: Heuristic Mean = $\bar{\bar{X}}_i$ = 90.19

Seed Mean = $\bar{\bar{X}}_j$ = 90.19

TABLE 8

F-4E TWO-FACTOR ANOVA TABLE

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-Statistic	α=.05 F-Critical
Between Rules (SSR)	r-1=4	26.936	6.734	5.669	$F^{4}_{12} = 3.26$
Between Seeds (SSC)	c-1=3	4.673	1.558	1.311	$F^{3}_{12} = 3.49$
Unexplained Residual (SEE)	(r-1)(c-1)=12	14.253	1.188	. . .	. . . . .
Sum of Squares Total (SST)	rc-1=19	45.863	. . .	. . .	. . . . .

NOTE:

Row (Rules)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$

H_1: At least one $\neq$

Decision Rule: If $F_s>F_c$, reject H_0

Rules: $F_s(5.69)>F_c(3.26)$

Therefore: H_0, significant at α=.05

Column (Seeds)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4$

H_1: At least one $\neq$

Decision Rule: If $F_s>F_c$, reject H_0

Rules: $F_s(1.555)<F_c(3.49)$

Therefore: Do not reject H_0, not significant at α=.05

TABLE 9

F-4E ONE-FACTOR ANOVA TABLE (AFTER COLLAPSING)

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-Statistic	$\alpha=.05$ F-Critical
Between Rules (SSR)	r-1=4	28.690	7.1724	5.52	$F^{4}_{15} = 3.06$
Unexplained Residual (SSE)	(c-1)+ (r-1)(c-1)=15	19.490	1.2992	. . .	. . . . . .
Sum of Squares Total (SST)	rc-1=19	48.180	. . .	. . .	. . . . . .

NOTES

Row (Rules)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$
H_1: At least one $\neq$

Decision Rule: If $F_s > F_c$, reject H_0

Rules: $F_s(5.52) > F_c(3.06)$

Therefore: Reject H_0, significant at $\alpha=.05$

TABLE 10

F-4E CALCULATION OF DIFFERENCE OF MEANS FOR SCHEFFE'S SIMULTANEOUS CONFIDENCE INTERVALS

$$(\mu_1-\mu_2) = (\bar{x}_1-\bar{x}_2) \pm \sqrt{[F_{.05,r-1,r(n-1)}](MSE)\frac{r-1}{n}(2)}$$

$$\mu_1-\mu_2 = (\bar{x}_1-\bar{x}_2) \pm 2.81988 = -2.240 \pm 2.81988$$

$$\mu_1-\mu_3 = (\bar{x}_1-\bar{x}_3) \pm 2.81988 = -3.010 \pm 2.81988$$

$$\mu_1-\mu_4 = (\bar{x}_1-\bar{x}_4) \pm 2.81988 = -1.625 \pm 2.81988$$

$$\mu_1-\mu_5 = (\bar{x}_1-\bar{x}_5) \pm 2.81988 = -3.42 \pm 2.81988$$

$$\mu_2-\mu_3 = (\bar{x}_2-\bar{x}_3) \pm 2.81988 = -.770 \pm 2.81988$$

$$\mu_2-\mu_4 = (\bar{x}_2-\bar{x}_4) \pm 2.81988 = .615 \pm 2.81988$$

$$\mu_2-\mu_5 = (\bar{x}_2-\bar{x}_5) \pm 2.81988 = -1.180 \pm 2.81988$$

$$\mu_3-\mu_4 = (\bar{x}_3-\bar{x}_4) \pm 2.81988 = 1.385 \pm 2.81988$$

$$\mu_3-\mu_5 = (\bar{x}_3-\bar{x}_5) \pm 2.81988 = -.410 \pm 2.81988$$

$$\mu_4-\mu_5 = (\bar{x}_4-\bar{x}_5) \pm 2.81988 = -1.795 \pm 2.81988$$

NOTE: $\bar{x}_1$ = Sample mean of MFCFS

$\bar{x}_2$ = Sample mean of FCFS

$\bar{x}_3$ = Sample mean of SMPT

$\bar{x}_4$ = Sample mean of LMPT

$\bar{x}_5$ = Sample mean of ETOC

TABLE 11

F-4E SINGLE PAIRWISE DIFFERENCE OF ROW MEANS

	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	$\bar{x}_5$
$\bar{x}_1$	0	-2.240	-3.010*	-1.625	-3.420*
$\bar{x}_2$	2.240	0	- .77	.615	-1.180
$\bar{x}_3$	3.010*	.770	0	1.385	- .410
$\bar{x}_4$	1.625	- .615	-1.385	0	-1.795
$\bar{x}_5$	3.420*	1.180	.410	1.795	0

*Indicates significant difference at α=.05.

TABLE 12

A-7D MANPOWER AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATIONS

Air Force Specialty Code	Shift Authorizations (24 One-Hour Shifts)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
322X1	6	6	6	6	6	11	11	11	11	11	11	11	11	11	11	11	11	6	6	6	6	6	6	6
325X0	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
325X1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
328X0	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2
328X1	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2
328X3	5	5	5	5	5	7	7	7	7	7	7	7	7	7	7	7	7	5	5	5	5	5	5	5
328X4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
404X1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
421X2	5	5	5	5	5	7	7	7	7	7	7	7	7	7	7	7	7	5	5	5	5	5	5	5
422X1	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
422X2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
423X0	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4
424X0	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2
431X1A	5	5	5	5	5	7	7	7	7	7	7	7	7	7	7	7	7	5	5	5	5	5	5	5
431X1F	39	39	39	39	39	40	40	40	40	40	40	40	40	40	40	40	40	39	39	39	39	39	39	39
431X1P	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
432X0	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
462X0	39	39	39	39	39	40	40	40	40	40	40	40	40	40	40	40	40	39	39	39	39	39	39	39
531X0	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1
532X0	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1
534X0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

TABLE 13

A-7D SPARE PARTS AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATIONS

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
11AEY	3	14GEC	3
11AAS	2	14GFC	8
11ABO	2	14GEJ	6
11BJB	3	14GFJ	3
12ABO	9	23000	8
12BAO	16	231UP	6
13ACB	46	231TN	2
13ABA	3	231TM	8
13BAB	3	231TL	8
13BBB	7	231WK	2
13CAA	6	231TA	2
13EAA	3	231UA	2
13EBJ	3	232FA	3
13ECA	2	23200	8
13FA9	8	233BC	1
13FAB	3	233CC	3
13FBB	2	233DC	6
14AAA	3	233AB	1
14BCR	9	233CB	6
14BBC	6	233EB	3
14BCP	3	233AA	8
14BCF	3	41AA9	7
14BCD	2	41AAC	6
14BCL	10	41AAL	3
14DCA	3	41ACR	7
14ECA	2	41ABA	6
14EDA	6	41ACA	6
14FBA	2	41EAF	6
14GEB	2	41EAB	6
14GEH	7	42AAA	8

TABLE 13--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
42BA9	8	51AEC	1
42BAF	3	51AAB	8
42BCC	3	51ADB	9
42BCA	16	51AEB	6
42CAA	7	51AAA	6
44AAA	8	51ABA	1
44AEA	10	51ADA	8
44AHO	7	51BAC	3
44AGO	6	51BAB	8
44BCC	6	57AAA	6
44BCK	19	57BAG	6
45AAE	8	57BAF	6
45AAD	3	57BAB	1
45AAB	1	57BBB	3
45AAK	1	57BCB	3
45ABA	8	57BCJ	3
45BAF	3	57CAO	3
45BAC	16	57CBO	6
45BAB	3	57CCO	6
45BAM	9	62AAO	11
45BBA	11	62ADO	1
45CAF	6	63AAO	16
45CAE	6	63AGO	7
45CAL	3	63AHO	6
45CAA	6	63BAO	11
45CBA	6	63BCO	9
46BBB	7	64AAO	11
46EBO	3	64ACO	9
46FAH	3	65AAO	18
46FBL	6	65ABO	17
47AAG	18	71AEA	6
47AAA	7	71ABO	11
47ABA	3	71ACO	10
47BAA	8	71AFO	8
51AED	7	71ADO	6

TABLE 13--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
71BAO	26	73BBO	8
71BCO	1	73CAO	8
71CAO	6	73DAO	8
71CFO	6	73DBO	3
72AAO	16	73DCO	6
72ABO	10	73EAO	8
72AEO	11	73EBO	8
72AHO	3	73FDE	3
73AJA	6	73FFC	13
73AAO	8	73FFA	1
73ABO	8	73FAO	8
73ACO	8	73FCO	1
73ADO	3	73FDO	8
73AEO	13	73GAO	8
73AFO	8	73GBO	3
73AJO	8	75ACO	8
73AKO	6	91AFC	7
73ALO	3		
73AMO	3		
73BAO	8		

TABLE 14

A-7D TWO-FACTOR ANALYSIS OF VARIANCE DATA

Heuristic	Seed				
	i=13	15	85	93	Heuristic Mean = $\bar{X}_i$
MFCFS	98.08	96.11	98.16	97.71	97.52 = $\bar{X}_1$
FCFS	92.33	92.17	91.41	92.16	92.02 = $\bar{X}_2$
SMPT	91.95	93.83	91.02	92.24	92.26 = $\bar{X}_3$
LMPT	94.75	92.22	89.55	94.09	92.65 = $\bar{X}_4$
ETOC	91.57	92.13	94.03	92.91	92.66 = $\bar{X}_5$
Seed Mean = $\bar{X}_j$	93.74	93.29	92.83	93.82	

NOTE: Heuristic Mean = $\bar{\bar{X}}_i$ = 93.42

Seed Mean = $\bar{\bar{X}}_j$ = 93.42

TABLE 15

A-7D TWO-FACTOR ANOVA TABLE

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-Statistic	α=.05 F-Critical
Between Rules (SSR)	r-1=4	84.993	21.248	10.652	$F^{4}_{12} = 3.26$
Between Seeds (SSC)	c-1=3	3.106	1.035	0.519	$F^{3}_{12} = 3.49$
Unexplained Residual (SSE)	(r-1)(c-1)=12	23.937	1.995	. . .	. . . . .
Sum of Squares Total (SST)	rc-1=19	112.036	. . .	. . .	. . . . .

NOTES

Row (Rules)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$

H_1: At least one $\neq$

Decision Rule: If $F_s > F_c$, reject H_0

Rules: $F_s(10.652) > F_c(3.26)$

Therefore: Reject H_0, significant at α=.05

Column (Seeds)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4$

H_1: At least one $\neq$

Decision Rule: If $F_s > F_c$, reject H_0

Seeds: $F_s(0.519) < F_c(3.49)$

Therefore: Do not reject H_0, not significant at α=.05

TABLE 16

A-7D ONE-FACTOR ANOVA TABLE (AFTER COLLAPSING)

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-Statistic	α=.05 F-Critical
Between Rules (SSR)	r-1=4	84.990	21.248	11.785	$F^{4}_{11} = 3.06$
Unexplained Residual (SSE)	(c-1)+ (r-1)(c-1)=15	27.043	1.803	. . .	. . . . .
Sum of Squares Total (SST)	rc-1=19	112.033	. . .	. . .	. . . . .

NOTES:

Row (Rules)

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$
H_1: At least one $\neq$
Decision Rule: If $F_s>F_c$, reject H_0
Rules: $F_s(11.785)>F_c(3.06)$
Therefore: Reject H_0, significant at α=.05

TABLE 17

A-7D CALCULATION OF DIFFERENCE OF MEANS FOR SCHEFFE's SIMULTANEOUS CONFIDENCE INTERVALS

$$(\mu_1-\mu_2) = (\bar{x}_1-\bar{x}_2) \pm \sqrt{[F_{.05,r-1,r(n-1)}](MSE)\frac{r-1}{n}(2)}$$

$\mu_1-\mu_2 = (\bar{x}_1-\bar{x}_2) \pm 3.3218 = 5.5000 \pm 3.3218$

$\mu_1-\mu_3 = (\bar{x}_1-\bar{x}_3) \pm 3.3218 = 5.2600 \pm 3.3218$

$\mu_1-\mu_4 = (\bar{x}_1-\bar{x}_4) \pm 3.3218 = 4.8700 \pm 3.3218$

$\mu_1-\mu_5 = (\bar{x}_1-\bar{x}_5) \pm 3.3218 = 4.8600 \pm 3.3218$

$\mu_2-\mu_3 = (\bar{x}_2-\bar{x}_3) \pm 3.3218 = -0.2400 \pm 3.3218$

$\mu_2-\mu_4 = (\bar{x}_2-\bar{x}_4) \pm 3.3218 = -0.6300 \pm 3.3218$

$\mu_2-\mu_5 = (\bar{x}_2-\bar{x}_5) \pm 3.3218 = -0.6400 \pm 3.3218$

$\mu_3-\mu_4 = (\bar{x}_3-\bar{x}_4) \pm 3.3218 = -0.3900 \pm 3.3218$

$\mu_3-\mu_5 = (\bar{x}_3-\bar{x}_5) \pm 3.3218 = -0.4000 \pm 3.3218$

$\mu_4-\mu_5 = (\bar{x}_4-\bar{x}_5) \pm 3.3218 = -0.0100 \pm 3.3218$

NOTE: $\bar{x}_1$ = Sample mean of MFCFS

$\bar{x}_2$ = Sample mean of FCFS

$\bar{x}_3$ = Sample mean of SMPT

$\bar{x}_4$ = Sample mean of LMPT

$\bar{x}_5$ = Sample mean of ETOC

TABLE 18

A-7D SINGLE PAIRWISE DIFFERENCE OF ROW MEANS

	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	
$\bar{x}_1$	0	5.500*	5.260*	4.870*	4.860*
$\bar{x}_2$	-5.500*	0	- .240	- .603	- .640
$\bar{x}_3$	-5.260*	.240	0	- .390	- .400
$\bar{x}_4$	-4.870*	.630	.390	0	- .010
$\bar{x}_5$	-4.860*	.640	.400	.010	0

*Indicates significant difference at α=.05.

TABLE 19

C-130E MANPOWER AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATIONS

Air Force Specialty Code	Shift Authorizations (Three Eight-Hour Shifts)		
325X0	3	3	4
325X1	5	5	6
328X0	6	5	7
328X1	9	11	11
328X4	2	2	2
421X1	8	8	10
421X2	9	8	9
422X1	4	6	6
423X0	8	9	9
424X0	8	9	9
431X1C	5	4	6
431X1D	2	2	0
431X1F	32	25	45
431X1P	5	15	0
432X0	15	13	15
531X0	0	2	0
532X0	0	1	0
534X0	7	8	7

TABLE 20

C-130E SPARE PARTS AUTHORIZATIONS (CONSTRAINTS) USED IN THE SIMULATION

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
11RAC	2	11541	6
11RAD	2	11543	3
11RAE	1	11548	4
11RAF	2	1154E	2
11RAG	1	1154G	3
11231	2	1154K	4
11234	3	1162E	2
11240	1	1163E	1
11241	1	12211	3
11244	2	12214	3
1124E	1	1221G	3
11271	3	1221Y	4
11280	1	1231B	4
11281	6	1231P	3
11283	2	1231S	4
1129H	6	1231T	2
11311	4	12414	1
11320	2	12511	3
11321	1	12518	1
11330	5	1251C	1
11331	2	1251H	3
11417	2	12615	3
1142W	2	12616	6
11435	3	12618	5
11438	1	1261B	3
11517	3	13111	5
1151M	1	1311A	4
1151P	1	1311B	6
1151V	4	1311M	1
11524	2	1311V	3
11525	1	13121	1
1152E	3	13211	2
1152K	2	13218	2
11536	2	1321A	1
11540	1	1321F	1

TABLE 20--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
13221	2	1442B	4
13413	1	22BAL	5
13414	3	22CAA	15
1342A	4	22EAP	2
1342C	9	22EBA	2
1342D	2	22EBC	7
1342E	5	22EBD	7
1342F	2	22EBL	3
13434	3	22FAA	1
1343A	3	22FAB	7
1343C	2	22FAD	3
1343F	6	22FAL	4
1343G	3	22FAM	1
13521	3	22GAA	27
13522	4	22GBA	5
13711	15	22GBE	13
13712	11	22GCA	11
13715	8	22GDA	3
1371C	5	22GBB	6
13721	44	22120	6
13722	13	22136	5
14131	2	22141	2
1413K	3	22144	8
1422B	3	2214B	2
1423J	3	22330	7
1424E	5	22514	2
14315	4	22516	4
1431A	4	22518	3
14338	3	2251B	5
1433J	4	2251E	5
14412	2	2251F	4
1441H	2	22532	2
1441S	1	2253A	3
1441T	1	22681	5
14427	2	22683	7

AD-A044 081 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 15/7
AN EVALUATION OF THE EFFECTS OF SELECTED SCHEDULING RULES ON AI--ETC(U)
JUN 77 W D DUNCAN, C H GWALTNEY

UNCLASSIFIED AFIT-LSSR-10-77A NL

2 OF 2
ADA
044081

END
DATE
FILMED
10-77
DDC

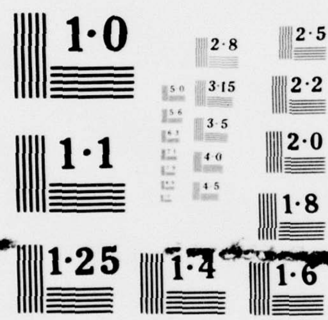

1·0
2·8
2·5
3·15
2·2
3·5
2·0
4·0
1·1
4·5
1·8
1·25
1·4
1·6

TABLE 20--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
2*BAL	1	3251U	6
2*BAR	1	3251V	5
2*EBC	4	3251W	5
2*EBD	2	3252E	9
2*136	4	3252N	23
2*141	1	32523	5
2*320	2	32525	11
2*333	2	3253C	12
2*41A	6	3253G	11
2*432	1	3253O	6
2*446	2	32536	3
2*514	5	32538	5
2*51B	4	32561	4
2*66H	6	41110	9
2*681	1	41121	7
2*683	37	41125	6
2*691	5	41142	8
24100	4	41212	11
24111	4	41213	6
24121	2	41221	7
24132	2	41223	7
2413F	1	41224	3
24142	2	41251	4
2414E	4	41252	4
2414K	4	41311	11
24151	3	41321	10
24158	3	41322	3
24164	5	41415	10
24210	1	41421	4
24216	5	41422	10
2421M	5	41424	7
32511	13	41428	5
3251R	7	41532	5
3251S	4	41533	4
3251T	12	41912	2

TABLE 20--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
41914	2	46625	3
4213A	12	46628	2
42155	1	47215	5
42210	1	47322	10
42212	3	47326	7
42213	2	4732F	6
4221C	4	4911E	3
42225	3	4911G	2
4222B	4	49128	9
4227C	3	49212	3
42324	5	49415	4
42624	4	49416	4
44125	5	49521	4
44130	6	51DDA	5
44291	3	51DDB	6
44310	7	51DDD	2
452AC	2	51111	6
452AJ	1	51113	7
453AA	7	5111B	4
453AF	9	51145	9
453AG	5	5114E	5
453AJ	1	5114F	3
454AA	4	5114J	6
456AB	5	5114K	5
456BB	5	51154	6
456CB	4	51821	9
46211	3	51822	17
46213	3	51823	13
46215	4	51824	3
46234	3	51825	16
46314	5	51826	32
46611	7	5182C	3
46613	14	5182D	3
46614	9	5182E	2
46621	6	51911	4

TABLE 20--Continued

Resource Identification Number	Authorized Quantity	Resource Identification Number	Authorized Quantity
52111	16	64211	2
52112	16	64212	6
52113	17	64213	7
52115	7	64217	7
52116	3	64218	2
52117	9	6421C	6
52118	9	6421D	5
5211R	7	65BAA	4
5211S	11	65BBO	4
52211	11	65EAA	2
52213	13	66171	13
52214	6	66172	11
52215	21	66173	18
52216	17	66174	8
5221B	7	66175	10
52311	17	66180	11
52312	7	66181	13
52320	7	66182	14
52410	8	71112	4
61214	12	71115	12
612AE	5	71116	4
62133	7	7111A	5
62134	6	71221	2
63112	4	7131C	5
63114	10	7131D	17
63117	3	7131E	4
6311A	6	7131J	3
63121	8	7131M	1
63123	2	71412	4
63125	2	71416	4
63131	6	71417	13
63141	5	71716	4
63151	6	71721	1
6315A	2	7211B	2
6351D	4	7211F	3

TABLE 20--Continued

Resource Identification Number	Authorized Quantity
72131	2
72132	3
72133	2
72134	2
72141	1
7215A	3
72752	3
72753	4
72755	3
72761	3
72764	2
72767	1
72768	1
72LAE	1
72LAG	3
72LAL	3
72LBA	9
72LCA	4
72LDO	4
72MBO	1
72MDO	1
72MEO	1
72MKO	1
72MLO	3
72MSO	1
72NAB	3
72NBO	10
72NCO	5
72RAA	5
72RBO	4
72RCO	7
72RFO	10
72RGO	20
72RKO	9
72RQO	21
72RRO	7
72771	2
72773	6
72774	4
72778	3
7277F	2
7277G	2
7277R	2
72781	5
72782	2
72785	3
72787	2
7278M	2
ENG	13
FCF 1	200
PHASE	200
*PROP	6

TABLE 21

C-130E ONE-FACTOR ANALYSIS OF VARIANCE DATA

Heuristic	Seed				
	i=13	15	85	93	Heuristic Mean = $\bar{X}_i$
MFCFS	77.34	73.97	76.97	. . .	76.09 = $\bar{X}_1$
FCFS	78.25	72.03	73.03	. . .	74.44 = $\bar{X}_2$
SMPT	. . .	76.09	79.16	71.31	72.19 = $\bar{X}_3$
LMPT	66.87	69.59	76.47	75.37	72.08 = $\bar{X}_4$
ETOC	73.16	. . .	69.84	79.97	74.32 = $\bar{X}_5$

NOTE: Heuristic Mean = $\bar{\bar{X}}_i$ = 73.82

TABLE 22

C-130E ONE-FACTOR ANOVA TABLE

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F-Statistic	α=.05 F-Critical
Between Rules (SSR)	$r-1=4$	37.408	9.352	.601	$F^{4}_{11} = 3.36$
Unexplained Residual (SSE)	$\sum_{i}^{r}(n_i-1)=11$	171.086	15.553	. . .	. . . . .
Sum of Squares Total (SST)	$\sum_{i}^{r} n_i-1=15$	208.494	. . .	. . .	. . . . .

NOTES:

<u>Row (Rules)</u>

H_0: $\mu_1=\mu_2=\mu_3=\mu_4=\mu_5$

H_1: At leat one ≠

Decision Rule: If $F_s>F_c$, reject H_0

Rules: $F_s(.601)<F_c(3.36)$

Therefore: Do <u>not</u> reject H_0, not significant at $\alpha=.05$

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Berman, M. B. *Improving SAC Aircrew and Aircraft Scheduling to Increase Resource Effectiveness.* RAND Corporation Report R-1435-PR. Santa Monica CA, November 1973.

2. Boyd, Major James A., Jr., USAF, and Major Gary J. Toy, USAF. "An Evaluation of the Use of the Logistics Composite Model to Measure the Effectiveness of Aircraft Flying Schedules." Unpublished master's thesis. SLSR 8-75B, AFIT/SL, Wright-Patterson AFB OH, 1975. AD A016267.

3. Boyett, Joseph Edward. "Effectiveness of Heuristics in a Dynamic Complex Assembly Shop." Unpublished Doctoral dissertation, School of Business, University of Colorado, 1972.

4. ________. "Maintenance Scheduling Limitations." Unpublished Technical Report, SLTR, AFIT/SL, Wright-Patterson AFB OH, 1973.

5. Bulkin, M. H., J. L. Colley, and H. W. Steinhoff, Jr., "Load Forecasting, Priority Sequencing, and Simulation in a Job Shop Control System," *Management Science*, October 1966, pp. B-29—B-51.

6. Clark, Charles T., and Lawrence L. Schkade. *Statistical Analysis for Administrative Decisions.* Chicago: South-Western Publishing Co., 1974.

7. Conway, R. W. *An Experimental Investigation of Priority Assignment in a Job Shop.* RAND Corporation Memorandum RM-3789-PR, Santa Monica CA, February 1964.

8. ________. *Some Tactical Problems in Simulation Method*, RAND Corporation Memorandum RM-3244-PR, Santa Monica CA, 1962.

9. ________, William Maxwell, and Louis W. Miller. *Theory of Scheduling.* Reading MA: Addison-Wesley Publishing Company, 1967.

10. Day, James E., and Michael P. Hottenstein. "Review of Sequencing Research," *Naval Research Logistics Quarterly*, XVII, No. 1 (March 1970), pp. 11-39.

11. Drake, William F. III, Air Force Maintenance and Supply Management Engineering Team, Wright-Patterson AFB OH. Personal interviews. Conducted intermittently from September 1976 through June 1977.

12. Elvers, Douglas A. "Job Dispatching Rules Using Various Delivery Date Setting Criteria," *Production and Inventory Management*, 4th Qtr. (1973), pp. 62-70.

13. Fisher, Captain, R. R., USAF, and others. *The Logistics Composite Model: An Overall View.* RAND Corporation Report RM-5544-PR, Santa Monica CA, May 1968.

14. Ginsberg, A. S., and B. King. *Base Operations-Maintenance Simulator.* RAND Corporation Memorandum RM-4072-PR, Santa Monica CA, 1964.

15. Glad, Major Richard F., USAF, and Major Robert T. Pierce, USAF. "A Comparison of Selected Scheduling Heuristics for a TAC F-4E Maintenance Organization." Unpublished master's thesis. SLSR-23-76B, AFIT/SL, Wright-Patterson AFB OH, 1976.

16. Hershaurer, James D., and Ronald T. Ebert. "Search and Simulation Selection of a Job-Shop Sequencing Rule," *Management Science*, Vol. 21, No. 7 (March 1975), pp. 833-845.

17. Jackson, J. R. "Simulation Research on Job Shop Production," *Naval Research Logistics Quarterly*, December 1957, pp. 287-295.

18. Kiviat, Phillip J. *Computer Assisted Maintenance Planning.* RAND Corporation Memorandum RM-4563-PR, Santa Monica CA, July 1965.

19. ________. *Manpower Requirements Prediction and Allocation for Unscheduled Maintenance on Aircraft.* RAND Corporation Memorandum RM-5215-PR, Santa Monica CA, February 1967.

20. Maxwell, W. L. *Priority Dispatching and Assembly Operations in a Job Shop.* RAND Corporation Memorandum RM-5370-PR. Santa Monica CA, October 1969.

21. Miller, L. W., A. S. Ginsberg, and W. L. Maxwell. *An Experimental Investigation of Priority Dispatching in Aircraft Maintenance, Using A Simplified Model.* RAND Corporation Report R-1385-PR, Santa Monica CA, June 1974.

22. Minh, Doan. "An Evaluation of Heuristic Scheduling Rules by Using a Zero-One Linear Programming Approach." Unpublished master's thesis, AFIT/SL Wright-Patterson AFB OH, 1975. AD A006348.

23. Neumann, Curtis E. *Priority Decision Rules in a Simulated Depot Component Repair Shop.* AFLC Report 70-13, Wright-Patterson AFB OH: AFLC, 1970, AD 715942.

24. New, C. C. "Job Shop Scheduling: Is Manual Application of Dispatching Rules Feasible?" *Operational Research Quarterly*, Vol. 26, No. 1 (I) (1975), pp. 35-43.

25. Randle, Captain John P., USAF. "A Review of the Use of Computer Simulation to Investigate Scheduling and Sequencing Problems." Unpublished master's thesis. SLSR-18-71A, AFIT/SL, Wright-Patterson AFB OH, 1975. AD 887480.

26. Rowe, A. J. "Sequential Decision Rules in Production Scheduling." Unpublished Ph.D. dissertation, UCLA, 1958.

27. Salter, Senior Master Sergeant Beverly A., USAF. Headquarters, Military Airlift Command, Scott AFB IL. Telephone interview. 21 September 1976.

28. Shannon, Robert E. "Simulation: A Survey with Research Suggestions," *AIEE Transactions.* September 1975, pp. 289-301.

29. Spinner, Allen H. "Sequencing Theory--Development to Date," *Naval Research Logistics Quarterly*, Vol. 15, No. 2 (June 1968), pp. 319-324.

30. Talbott, Captain Carlos M., USAF. Logistics Management Center. Gunter AFB AL. Telephone interview. Conducted during August 1976.

31. U.S. Air Force Logistics Command, Research Division (MCCTR). *Logistics Composite Model Users Reference Guide.* AFLC Report 70-1, January 1970. Wright-Patterson AFB OH: AFLC, 1970.

32. U.S. Department of the Air Force. *Maintenance Management.* AFM 66-1, Vol. I. Washington: Government Printing Office, 1 May 1974.

33. ________. *Maintenance Management.* AFM 66-1, Vol. II. Washington: Government Printing Office, 1 May 1974.

34. ________. *A Study of the Automation of the Logistics System at Base Level.* Vol. I: "Study Findings." Washington: HQ USAF, 1973.

35. U.S. Tactical Air Command. *Logistics Composite Model (L-COM) Study.* Vol. I and Vol. II. Langley AFB VA: HQ TAC, 1973.

36. Wonnacott, Thomas H., and Ronald T. Wonnacott. *Introductory Statistics for Business and Economics.* New York: John Wiley and Sons, Inc., 1972.

37. Yates, Captain Gerald A., USAF, and First Lieutenant Richard Fritz, USAF. "A Computer Simulation of Maintenance Manpower Requirements for the DC-130H." Unpublished master's thesis. GOR-SM-75D-5, AFIT/ENS, Wright-Patterson AFB OH, 1975. AD A020229.

38. York, Major Michael F., USAF. Headquarters, Tactical Air Command, Langley AFB VA. Telephone interview. 15 February 1977.

B. RELATED SOURCES

Ambre, William A., Major, USAF. "Scheduling Rules for Aircraft Maintenance." Unpublished master's thesis LD 31630, Air Command and Staff College, Air University, 1974.

Conner, John L. "A Heuristic Method for Solving Job Shop Sequencing Problems," *Production & Inventory Management*, 1st Qtr. (1972), pp. 54-68.

Conway, Richard W. "Priority Dispatching and Job Lateness in a Job Shop," *The Journal of Industrial Engineering*, Vol. XVI, No. 4 (July-August 1965), pp. 228-237.

________. "Priority Dispatching and Work-in-Process Inventory in a Job Shop," *The Journal of Industrial Engineering*, Vol. XVI, No. 2 (March-April 1969), pp. 124-130.

Fisherman, George S. *Problems in the Statistical Analysis of Simulation Experiments: The Comparison of Means and the Length of Sample Records.* RAND Corporation Report RM-4880-PR, Santa Monica CA, February 1966.

Hollaway, C. A. and R. T. Nelson. "Job Shop Scheduling with Due Dates and Overtime Capability." *Management Science.* Vol. 21, No. 1, September 1974, pp. 68-78.

McMahon, Graham and Michael Florian. "On Scheduling with Ready Times and Due Dates to Minimize Maximum Lateness," *Operations Research.* Vol. 23, No. 3 May-June 1975, pp. 475-82.

Newson, E. F. Peter. "Multi-Item Lot Size Scheduling by Heuristic Part I: With Fixed Resources." *Management Science.* Vol. 21, No. 10, June 1975, pp. 1186-1203.

O'Brian, James T. *Scheduling Handbook.* New York: McGraw-Hill Book Company, 1969.

U.S. Department of the Air Force. *A Study of the Automation of the Logistics System at Base Level.* Vol. VI: "Executive Brief." Washington: HQ USAF, 1973.

________. Air Force Logistics Command, Systems Requirements and Control Division (ADDR), Office of the DCS/Data Automation. *Logistics Composite Model Users Reference Guide Update.* AFLC/ADDR Report 74-1, November 1974. Wright-Patterson AFB OH: AFLC, 1974.

Vergin, Roger C. A note on "Lot Size Scheduling on a Single Machine for Stochastic Demand" by Goyal. *Management Science*. Vol. 22, No. 7, March 1976, pp. 823-24.